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Identifying a Forward-Looking Monetary Policy in an Open Economy

Rokon Bhuiyan
QED

Department of Economics
Queen's University
94 University Avenue
Kingston, Ontario, Canada
K7L 3N6

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Rokon Bhuiyan*

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Abstract. I identify a forward-looking monetary policy function in a structural VAR model by using forecasts of macroeconomic variables, in addition to the realized variables used in a standard VAR. Both impulse responses and variance decompositions of the monetary policy variable of this forecast-augmented VAR model suggest that forecasted variables play a greater role than realized variables in a central bank's policy decisions. I also find that a contractionary policy shock instantaneously increases the market interest rate as well as the forecast of the market interest rate. The policy shock also appreciates both the British pound and the forecast of the pound on impact. On the other hand, the policy shock lowers expected inflation immediately, but affects realized inflation with a lag. When I estimate the standard VAR model encompassed in the forecast-augmented model, I find that a contractionary policy shock raises the inflation rate and leads to a gradual appreciation of the domestic currency. However, the inclusion of inflation expectations reverses this puzzling response of the inflation rate, and the inclusion of both the market interest rate forecast and the exchange rate forecast removes the delayed overshooting response of the exchange rate. These findings suggest that a standard VAR may incorrectly identify the monetary policy function.

JEl classification: C32, E52, F37

Keywords: Forward-looking monetary policy, forecast-augmented VAR, impulse response

*Ph.D. Candidate, Department of Economics, Queen's University, Kingston, Ontario, Canada. Email: rokon.bhuiyan@econ.queensu.ca. I thank Gregor Smith for many helpful suggestions. I also thank Allan Gregory, Robert Lucas, Allen Head, Bev Lapham, Thor Koeppl, Huw Lloyd-Ellis, Marco Cozzi, Tao Zha, David Cushman, Joel Rodrigue, Mario Crucini, Jean Boivin, and seminar participants at Queen's University and the Canadian Economics Association Meetings for comments.

"If we wait until a price movement is actually afoot before applying remedial measures, we may be too late." —John Maynard Keynes, 1924, *Tract on Monetary Reform.*

"The challenge of monetary policy is to interpret current data on the economy and financial markets with an eye to anticipating future inflationary forces and countering them by taking action in advance." —Alan Greenspan, 1994, *Humphrey-Hawkins Testimony.*

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1. Introduction

Econometricians can identify monetary policy shocks in a VAR model by conditioning the policy reaction function on a set of macroeconomic variables. However, to the extent that central banks and the private sector have information not reflected in the VAR, the measurement of an econometrician's policy innovations will be contaminated. Since monetary policy in practice is driven largely by anticipated future outcomes (especially for the central banks that target inflation), a standard VAR model, which uses *ex post* realized data of macroeconomic variables, identifies a policy function that is different from that of central banks. As a consequence, these standard models may estimate erroneous policy shocks and hence generate misleading impulse responses.

To overcome this problem, I formulate a forward-looking monetary policy function in a structural VAR model by using forecasts of a number of key macroeconomic variables, in addition to the realized variables used in a standard VAR. Since this forecast-augmented VAR model uses both forecasted and realized variables, and the standard model uses only realized variables, the latter model is nested in the former model. The forecast-augmented VAR model, apart from identifying a forward-looking policy function, provides a number of other advantages over a standard VAR model. First, since the macroeconomic forecasts I employ to identify monetary policy in the forecast-augmented model are based on many other variables that central banks and the private sector might observe, the identified policy function spans a bigger information set, without estimating a large model. Second, the estimated impulse response function of the monetary policy variable gives us an opportunity to examine how central banks, especially inflation-targeting central banks, react to shocks to inflation expectations or other forecasts that embody information about future inflation. Third, by contrasting the impulse response of the policy variable due to shocks in forecasted and realized variables, we can examine to which variables the central bank responds more significantly in designing monetary policy. Similarly, by observing the variance decomposition, we can examine the proportions of the movements in the policy variable explained by forecasted variables relative to realized variables. Fourth, by comparing impulse responses of forecasted and realized variables due to shocks to the policy variable, we can observe whether monetary policy affects these two types of variables differently. Finally, since the forecast-augmented model encompasses the standard model, by estimating both models, we can understand the contributions of identifying the forward-looking monetary policy using forecasted variables.

I apply this forecast-augmented VAR model to the Bank of England, which was one of the first central banks to target inflation. The macroeconomic forecasts I employ as inputs to the policy reaction function of the Bank are the forecasts of the inflation rate, the market interest rate, the exchange rate, and the US federal funds rate. I obtain inflation forecasts from the Bank of England's statistics department, which uses prices of inflation-indexed bonds to calculate market participants' expectations about the future inflation rate. I obtain interest rate forecasts and exchange rate forecasts from the FX4casts, a commercial firm that collects these forecasts from different professional forecasters. Finally, I calculate federal funds rate forecasts by observing market prices of federal funds futures from Bloomberg.

Since the UK is an open economy, I assume that the Bank of England also responds to a vector of foreign variables including the US and German monetary policy variables. To develop the structural VAR model, I follow the general procedure of Cushman and Zha (1997) but change it in a number of respects. First, unlike these authors, I do not use money in my model and therefore do not define a money demand function or a money supply function. Instead, I use the bank rate as the policy instrument, which is what the Bank uses to conduct monetary policy. I argue that unlike money and market interest rates, which were used as policy instruments in most previous VAR studies, the bank rate cannot be influenced by private-sector behaviour, except through the endogenous policy response of the Bank. Therefore, estimated policy innovations using the bank rate are more precise measures of exogenous monetary policy shocks. Second, in order to make the identification more realistic, I allow more contemporaneous interaction among the variables used in the model. Third, since the over-identified forecast-augmented VAR model developed in this paper entails simultaneous interactions, in order to obtain accurate statistical inference, I employ the Bayesian Gibbs sampling estimation method of Waggoner and Zha (2003), who incorporated prior information into the VAR as suggested by Sims and Zha (1998).

Two specific results of the forecast-augmented model suggest that forecasted variables play a greater role than realized variables in identifying the monetary policy function and that the Bank of England conducts a forward-looking monetary policy. First, the impulse response of the bank rate suggests that monetary policy responds to shocks to inflation expectations and other macroeconomic forecasts more significantly than shocks to corresponding realized variables. Second, the variance decomposition also shows that shocks to inflationary expectations and other forecasts explain a higher proportion of the movements of the policy variable than do shocks to realized variables. These findings are consistent with the Bank's inflation-targeting monetary policy, that is, designing current policy based on the projections of the future economy in order to achieve the target inflation rate.

I also find that a contractionary policy shock of raising the bank rate almost instantaneously increases the market interest rate as well as the forecast of the market interest rate. This policy shock also appreciates both the British pound and the forecast of the pound on impact. Although the policy shock has a similar type of effects on the financial variables and their forecasts, the same is not true for the actual inflation rate and the forecast of the inflation rate. While the contractionary policy shock lowers the expected inflation rate almost immediately, the shock does not have a significant effect on the actual inflation rate until the beginning of the second year. The quicker response of inflation expectations reflects the credibility of the Bank of England's monetary policy: the public trusts the Bank's action will bring today's higher inflation down to the target level in the future, so they expect a lower inflation rate in the future. I also find that the contractionary policy shock lowers the level of output with a lag of about one year.

When I estimate the standard model nested in the forecast-augmented I find that, while the pattern of the impulse responses of the market interest rate and output remains unchanged from that of the forecast-augmented model, there is a remarkable change in the impulse responses of the realized inflation rate and the exchange rate. Due to a contractionary monetary policy shock in the standard model, the realized inflation rate increases and remains significant for about one year. This response is at odds with what we expect from a contractionary policy shock. On the other hand, following the same shock, the British pound keeps appreciating for about six months after the shock. This response is inconsistent with Dornbusch's (1976) prediction that following a contractionary policy shock the exchange rate overshoots its long-run level on impact, followed by a gradual adjustment to the initial value.

To examine which aspect of the forecast-augmented model absent from the standard model causes these puzzling responses, I put the forecasted variables into the standard model one after another. I find that the incorporation of the inflation forecast into the standard VAR reverses the puzzling response of the inflation rate, and the inclusion of both the market interest rate forecast and the exchange rate forecast removes the delayed overshooting response of the exchange rate. These findings confirm the importance of identifying a forward-looking monetary policy reaction function using forecasts of macroeconomic variables as inputs.

The remainder of the paper is organized as follows: section 2 presents the context of the research, section 3 provides the data sources, section 4 describes the structural VAR models, section 5 presents the results, and section 6 draws conclusions.

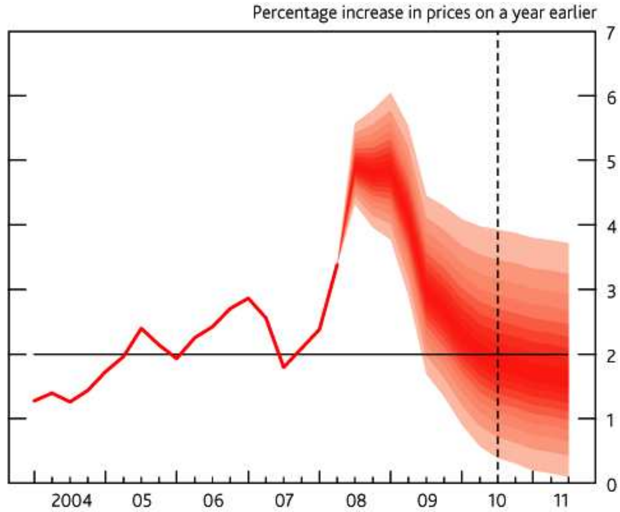
2. Research Context

Svensson (1997, 2000) argues that current variables are relevant to the monetary authority only to the extent that they help to forecast an economy's expected future evolution. Empirically estimated single-equation monetary policy functions, such as those of Clarida, Galí, and Gertler (2000), Orphanides (2001), and Nelson (2001), suggest that policy reaction functions based on realized revised data yield misleading descriptions of historical monetary policy, and forward-looking specifications describe monetary policy better than Taylor-type specifications. Monetary policy simulations using econometric models imply that central banks implement a forward-looking policy rule with a forecast horizon of about two years in the future (see, for example, Coletti, Hunt, Rose, and Tetlow (1996) for the Bank of Canada and Black, Cassino, Drew, Hansen, Hunt, Rose, and Scott (1997) for the Reserve Bank of New Zealand).

The practice of conducting forward-looking monetary policy has become further explicit since the early 1990s when many industrialized nations, such as the UK, New Zealand, Sweden, Canada, and Australia, officially adopted an inflation-targeting monetary policy. The operating procedure of the inflation-targeting approach is known as inflation-forecast targeting. As explained by Woodford (2007), under this approach, the central bank constructs quantitative projections of the economy's expected future evolution to design its current monetary policy. While some nations practice an explicit target for future inflation to conduct monetary policy, most others, including the US, also make forecast-based decisions without such an explicit target for inflation. In 2004 when he was a member of the Board of Governors, Ben Bernanke, the current chairman of the US Federal Reserve, said that the Fed primarily relies on the forecast-based approach for making policy.

The inflation-targeting approach involves a high degree of transparency and accountability on the part of central banks to the public. For example, the Bank of England publishes a quarterly *Inflation Report* that contains a chart, as shown in figure 1, in order to give an overview of the justification of the Bank's current monetary policy stance to the public. This fan chart, as of August 2008, indicates the probability distribution of possible evolutions of future inflation over the next three years, with the modal projection indicated by the most deeply shaded region. These projections are made based on the Bank's forecasts about the market interest rate and the exchange rate. If, for whatever reason, the inflation rate deviates more than one percentage point from the target rate of two percent, the Governor of the Bank of England is required to write an open letter explaining the reasons for divergence and the steps the Bank will undertake to bring the inflation rate back to two percent. Due to such a high degree of accountability and transparency, market participants are also aware of the projections of the future economy and can guess the probable policy actions of the monetary authority.

Figure 1: August 2008 Inflation Forecasts of the Bank of England



Since the central bank emphasizes the projections of the economy's future evolution, an econometrician also needs to identify a forward-looking monetary policy function. The importance of identifying the policy function by incorporating correct information can be illustrated by Sims's (1992) explanation of the so-called price puzzle. Sims argues that if a central bank systematically tightens monetary policy anticipating future inflation, but an econometrician does not capture these inflationary signals, then the estimated policy shock in the VAR may in fact be the monetary authority's response to inflationary expectations. This explains the empirical finding of the increase in the price level following a contractionary policy shock, since the policy response is likely to partially offset the inflationary pressure. If this explanation for the price puzzle is correct, then all estimated impulse responses in traditional VAR models are incorrect. In reality, however, in addition to inflation expectations, forecasts of other macroeconomic variables, such as output, interest rates, and exchange rates, are also crucial considerations of central banks' policy decisions. Therefore, a VAR model that does not include these forecasts in the estimation process might also generate misleading results.

Some previous studies have also attempted to identify monetary policy functions by including future information into the VAR model. Sims and Zha (1995) suggested using a proxy variable that might contain information about the future inflation of the economy. Khan, Kandel, and Sarig (2002) and Bhuiyan and Lucas (2007) used measures of inflationary expectations as inputs to the monetary policy rule in a three-variable recursive VAR model. In a different approach to the same problem, Tharpar (2008) constructed forecast errors by replacing VAR-based forecasts with Greenbook forecasts. She then identified exogenous monetary policy shocks from the constructed forecast errors, assuming these Greenbook forecasts are more informative than VAR-based forecasts.

While the use of inflation expectations, or any proxies for inflation expectations, in these studies is a step towards identifying monetary policy correctly, the omission of other macroeconomic forecasts might also lead to erroneous policy innovations. Furthermore, the recursive approach used in these studies cannot incorporate the contemporaneous interrelationships among the variables used in the model. These recursive studies either assume that the market interest rate and the exchange rate do not react to the policy variable or that the policy variable does not respond to these macroeconomic variables within the month. In reality, however, the policy variable, the market interest rate, and the exchange rate interact with each other almost instantaneously. These studies also assume that non-US central banks do not respond to the Fed policy move until a month later, which is particularly inappropriate for an open economy like the UK. Another limitation of most previous VAR studies is that the smaller number of variables used in the model is unlikely to span the information used by central banks and the private sector.

Given the preceding literature, I make a number of contributions in this paper. First, I employ more forecasted variables as inputs to the monetary policy function. I assume that, in addition to inflation forecasts, central banks might observe other macroeconomic forecasts to make policy decisions. Therefore, the omission of these variables will also misidentify the policy reaction function. Second, since the macroeconomic forecasts used in this paper embody indirect information about many other domestic and foreign variables, the identified monetary policy function using these forecasts spans a bigger information set. Therefore, the proposed forecast-augmented VAR model is an alternative to Bernanke, Boivin, and Eliasz's (2005) factor-augmented VAR model that exploits indices of the dynamic factor model in order to condition the monetary policy function on a bigger information set. Third, since the forecast-augmented VAR model uses both forecasted and realized variables, I can examine which type of variables plays a greater role in monetary policy decisions. The forecast-augmented model also allows me to investigate whether the central bank reacts to and affects the forecasted and the realized variables differently. Fourth, since the forecast-augmented VAR model encompasses the standard VAR model, by estimating both models, we can understand the contributions of identifying the forward-looking monetary policy using forecasted variables. Finally, in order to make the identification more realistic, I develop my structural VAR models in an open-economy context, allowing more simultaneous interactions among the contemporaneous relationship of the variables. And, in order to obtain accurate statistical inference from these over-identified structural VAR models with simultaneous interactions, I employ a Bayesian Gibbs sampling method to estimate the posterior distribution of the parameters.

3. Monthly Data for the UK

In this section, I describe the forecasted and realized macroeconomic variables and their sources. The data runs monthly from October 1988 to June 2008. For ease of understanding, I categorize the variables used in this paper into four broad types: the policy variable, the forecasted variables, the domestic realized variables, and the foreign realized variables. The policy variable is the bank rate, i_m, of the Bank of England. The block of forecasted variables, x^f, includes inflation rate forecasts, π^f; market interest rate forecasts, i^f; exchange rate forecasts, s^f; and US federal funds rate forecasts, i_u^{*f}. Although the series of gross domestic product (GDP) forecasts is a good candidate to be included in the block of the forecasted variables, the monthly GDP forecast with a constant horizon is unavailable. Therefore, I do not include the GDP forecast in this block. The vector of the domestic realized variables, x^r, includes the inflation rate, π; the gross domestic product (GDP), y; the market interest rate, i; and the exchange rate, s, while the block foreign variables, x^*, are the US federal funds rate, i_u^*; the US inflation rate, π_u^*; the US industrial production, y_u^*; the German interest rate, i_g^*; the German inflation rate, π_g^*; and the German industrial production, y_g^*.

I obtain the bank rate from the Bank of England's website (http://www.bankofengland.co.uk/monetarypolicy/decisions.htm). The inflation forecast, more precisely known as the break-even inflation rate, is a market-based measure of the expected inflation rate. I obtained this two-year horizon expected inflation rate series from the statistics department of the Bank of England.[1] The Bank calculates inflation expectations on a daily basis by observing market prices of indexed bonds and returns from nominal government bonds, following both the spline-based method (put forward by Waggoner (1997)) and the parametric method (put forward by Svensson (1994)).

[1]I thank Iryna Kaminska of the Bank of England for providing me with the data.

Until recently, the Bank of England was calculating inflation expectations employing Svensson's (1994) parametric method subject to some modifications proposed by Deacon and Derry (1994) due to the eight-month lag in indexation of the coupon payments. To implement this method, the Bank first estimated the nominal term structure in the usual way to obtain an implied nominal forward rate curve. The Bank then fitted a real forward curve to prices of index-linked bonds using an initial assumption of market inflation expectations. Finally, the Bank applied the Fisher identity to each pair of points along the nominal and real forward rate curves in order to estimate a new measure of inflation term structure. In the second round, the Bank used the estimated inflation term structure to re-estimate the real forward curve and compared this curve with the nominal interest rate curve to derive a revised estimate of the inflation term structure. This iterative procedure continued until the inflation term structure converged to a single curve. To derive these inflation term structures, the Bank assumed that there is no inflation risk premium so that the nominal forward rate equals the sum of the real rate and the expected inflation rate.

Recently, the Bank of England has been calculating inflation expectations following Waggoner's (1997) spline-based method subject to some modifications proposed by Anderson and Sleath (2001). The spline-based method also uses nominal and index-linked bonds to derive nominal and real yield curves, and then employs the Fisher relationship to estimate inflation expectations. The basic idea of the spline-based method is that rather than specifying a single functional form to fit forward rates as does Svensson (1994), it fits a curve to the data that is composed of many segments, with constraints imposed to ensure that the overall curve is continuous and smooth.[2]

These measures of inflation expectations are regularly presented to the Bank's Monetary Policy Committee (MPC) to inform the current assessment of future economic conditions. In order to increase the precision of the policy identification in my model, I collect the dates of the MPC meetings from the Bank's website(http://www.bankofengland.co.uk/monetarypolicy /decisions.htm) and use the inflation expectation rate calculated immediately before the meeting day. The daily-basis calculation of inflation expectations allows me to use the latest inflation expectations as input to the policy function. In my sample, I use the parametric method's inflation expectations from 1988 until 2004, when the Bank stopped producing this series. For the rest of the sample I use spline-based inflation expectations, since the Bank has been employing these inflationary expectations in recent years. Unfortunately, due to the unavail-

[2]For a detailed explanation of the spline-based method, see Anderson and Sleath (2001) and for the parametric method, see Deacon and Derry (1994).

ability of indexed bonds of maturity less than two years, I cannot use inflation expectations of any shorter horizon. However, as an input to monetary policy, the expected inflation rate of two-year horizon is more suitable than that of most other horizons since a rough benchmark is that monetary policy shocks affect inflation with a lag of about two years.

I obtain survey-based forecasts of the three-month horizon market interest rate and the three-month horizon exchange rate from a private firm, FX4casts. Each month FX4casts asks 45 different professional forecasters to provide their forecasts of exchange rates and 18 different professional forecasters to provide their forecasts of market interest rates for the end of the three-month horizon. FX4casts then calculates the geometric mean of these forecasts, which are commercially available for business entities and researchers.The other forecasted variable I use is public expectations about the future US federal funds rate, which I derive from 30-day federal funds futures traded at the Chicago Board of Trade. I collect these prices from Bloomberg. Then, assuming risk neutrality, I estimate a measure of federal funds rate expectations at a one-month horizon by deducting prices of these futures from 100. Table 1 summarizes the forecasted macroeconomic variables used in this paper.

Table 1: Data Sources and Definitions of the Forecasted Variables

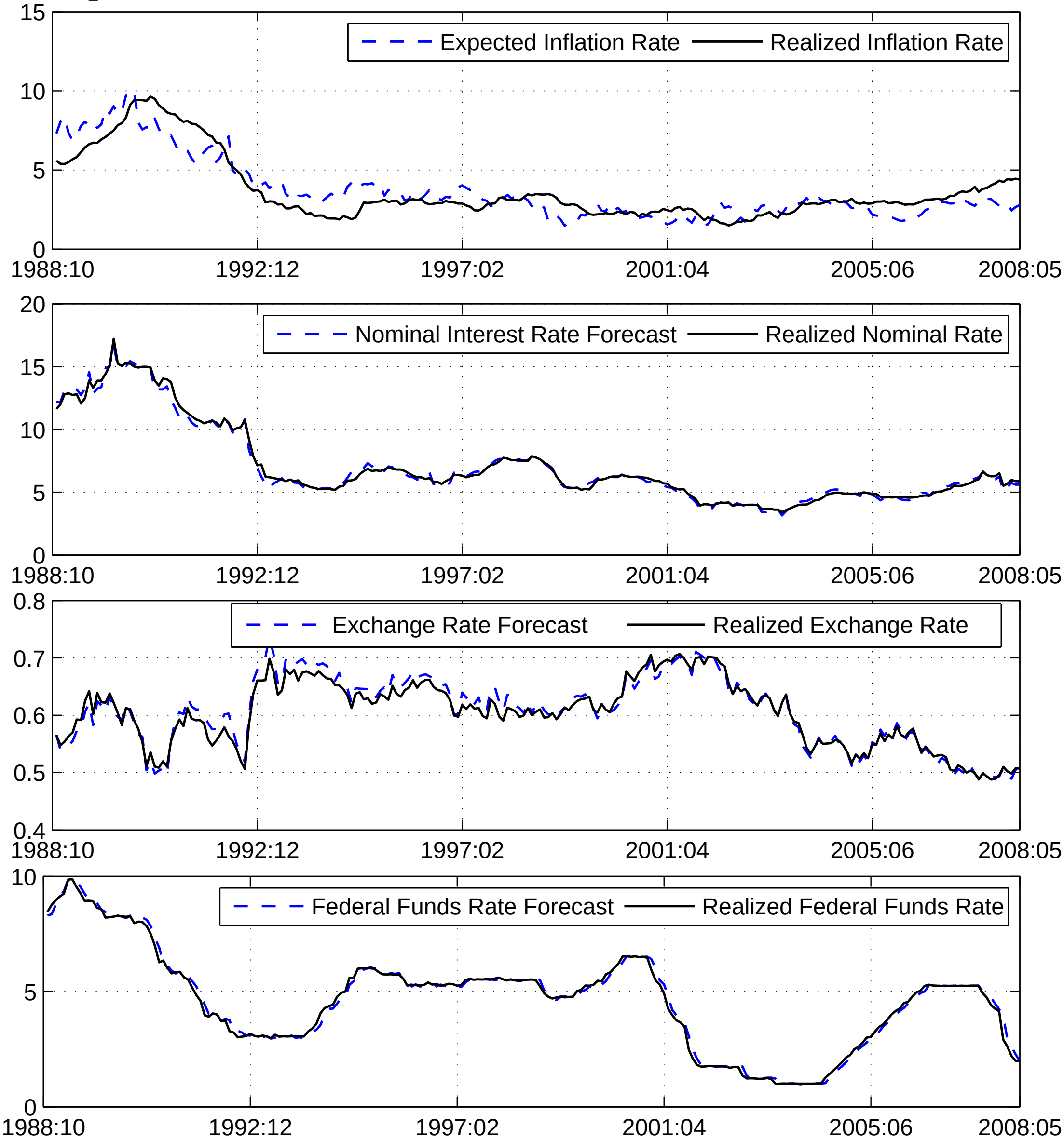
Variable	Definition	Forecast Horizon	Source
π^f	Expected Inflation Rate	2 Years	Bank of England
i^f	Interest Rate Forecast	3 Months	FX4casts
s^f	Exchange Rate Forecast	3 Months	FX4casts
i^{*f}	US Federal Funds Rate Forecast	1 Month	Bloomberg

I collect the monthly UK GDP from the National Institute of Economic and Social Research (NIESR).[3] I obtain all other variables from the *International Financial Statistics* of the International Monetary Fund. The labels of these variables are as follows: i, the UK market interest rate (IFS, 11260C..ZF..); π, the annualized monthly inflation rate calculated from the UK retail price index (RPI) (IFS, 11264..ZF..); s, the logarithm of the nominal exchange rate in units of British pounds per US dollar (IFS, 112..AC..ZF); i^*_u, the US federal funds rate

[3] I thank James Mitchell of the NIESR for providing me with the GDP data. See Mitchell, Smith, Weale, Wright, and Salazar (2005) for a detailed explanation of how the monthly GDP series is calculated.

(IFS, 11164B..ZF..); y_u^*, the logarithm of US industrial production (IFS, 11166..CZF..); π_u^*, the annualized monthly US inflation rate calculated from the US consumer price index (IFS, 11164..ZF..); i_g^*, the Bundesbank rate (IFS, 13460B..ZF..); y_g^*, the logarithm of German industrial production (IFS, 13466...ZF..); and π_g^*, the annualized monthly German inflation rate calculated from the German consumer price index (IFS, 13464...ZF..).

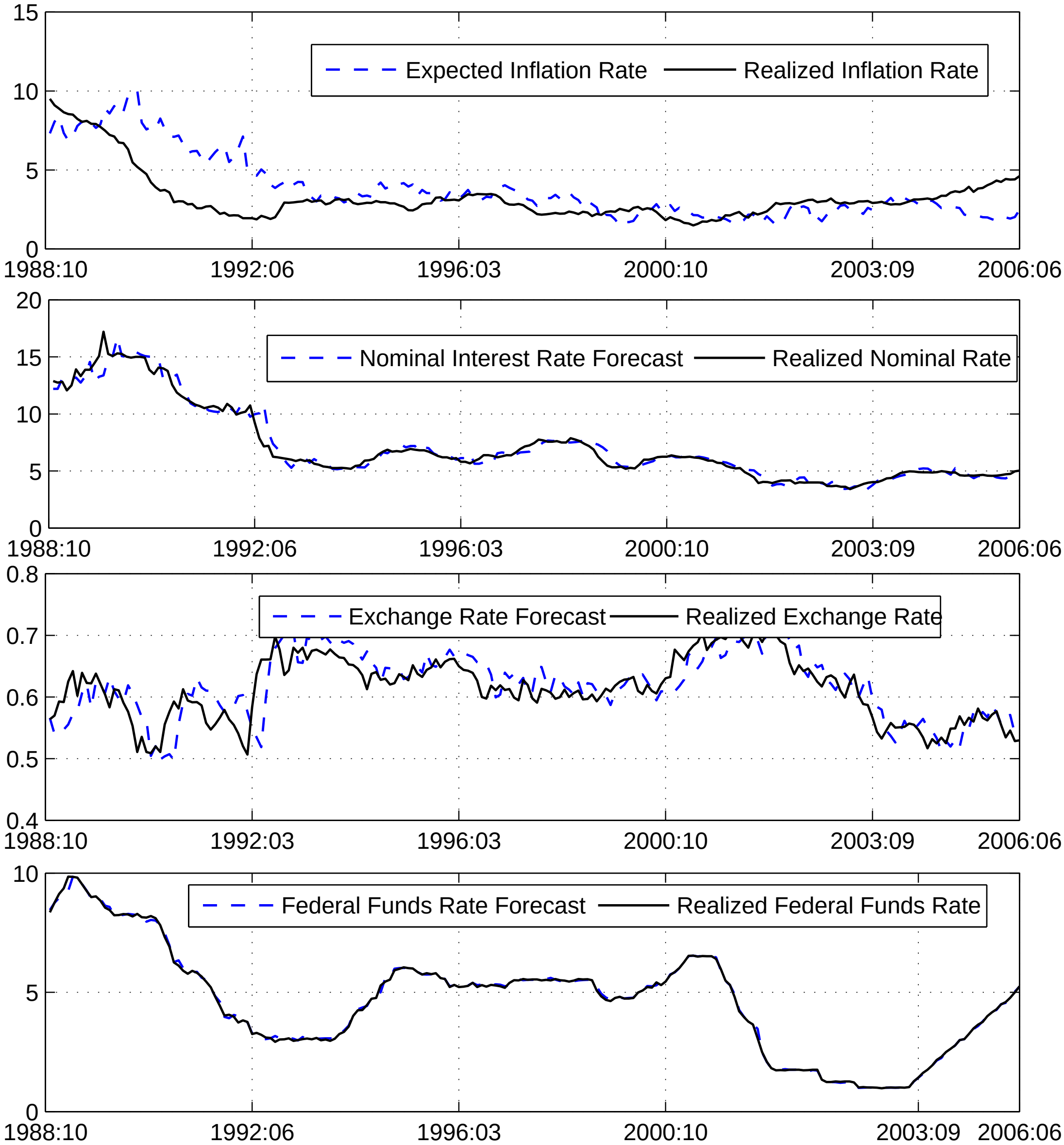
Figure 2: Forecasted Vs. Realized Variables: Information Difference



Note: At each point of time, the figure compares the realized value of a variable with the value forecasted at that time for the future. The vertical distances between the solid and dashed lines in every panel measure the difference in information in the policy reaction function identified in the forecast-augmented VAR model compared to that in a standard VAR model.

Next, I plot the forecasted variables against the corresponding realized variables in figure 2. The series plotted in this figure are used in the estimation process of the forecast-augmented model. At each point of time, figure 2 compares the realized value of a variable with the value forecasted at that time for the future. Therefore, the vertical distances between the solid and dashed lines in every panel of the figure measure the difference in information between the forecasted and realized variables. Hence, these vertical distances also measure the difference in information in the policy reaction function identified in the forecast-augmented VAR model compared to that in a standard VAR model.

Figure 3: Forecasted Vs. Realized Variables: A Comparison



Note: At each point of time, the figure plots the realized values of a variable against the values forecasted for that variable in the past. The vertical distances between the solid and dashed lines measure forecast errors of the variables.

On the other hand, figure 3, at each point of time, plots the realized values of a variable against the values forecasted for that variable in the past. Therefore, the vertical distances between the solid and dashed lines measure forecast errors of the variables. Figure 3 shows that the forecasts of the financial variables (the market interest rate, the exchange rate, and the federal funds rate) track the corresponding realized variables more closely than does inflation expectations track realized inflation. This difference in tacking might be due to the shorter forecast horizon of the financial variables than the inflation rate. Figure 3 also shows that expected inflation over predicted actual inflation during the early 1990s, but under predicted in recent years. The over-prediction during the early 1990s might reflect the public's mistrust of the Bank's commitment to a low inflation rate due to the history of high inflation. On the other hand, the under-prediction in recent years might reflect the credibility of the central bank: the public trust that the Bank will take action to bring today's higher inflation back to the target level, so the public expects a lower inflation rate for the future.

4. A Structural VAR Model

Subsection 4.1 develops the forecast-augmented structural VAR model that encompasses both the forecast-based VAR model and the traditional VAR model. Subsection 4.2 then describes a Bayesian Gibbs sampling method to estimate these models.

4.1 Identification of the Forward-Looking Monetary Policy

Omitting constant terms, a typical structural VAR system can be written in the following linear and stochastic dynamic form:

$$Ax_t = \sum_{l=1}^{p} B_l x_{t-l} + \varepsilon_t, \tag{1}$$

where x_t is an $n \times 1$ column vector of endogenous variables at time t, A and B_l are $n \times n$ parameter matrices, ε_t is an $n \times 1$ column vector of structural disturbances, p is the lag length, and $t = 1, ..., T$, where T is the sample size. The parameters of the individual equations in the structural VAR model (1) correspond to the rows of A and B_l. I assume that the structural disturbances have a Gaussian distribution with $E(\varepsilon_t \mid x_1, ..., x_{t-1}) = 0$ and $E(\varepsilon_t \varepsilon_t' \mid x_1, ..., x_{t-1}) = I$. For the sake of clarity, I rewrite the structural system (1) in the following matrix notation:

$$Ax_t = Bz_t + \varepsilon_t, \tag{2}$$

where $z_t = [x_{t-1} .... x_{t-p}]'$ and $B = [B_1 .... B_p]$. Here z_t is the $np \times 1$ column vector of all lagged variables and B is the $n \times np$ matrix of all lagged coefficients.

Let us assume that the structural model (2) is the forecast-augmented VAR model that also encompasses the standard VAR model. Then, as mentioned in the previous section, the vector of endogenous variables x comprises four blocks of variables—the first block consists of the monetary policy instrument of the central bank, i_m, the second block includes the forecasted macroeconomic variables, x^f:$[\pi^f, i^f, s^f, i_u^{*f}]$, the third block comprises the realized macroeconomic variables, x^r:$[\pi, y, i, s]$, and the fourth block consists of the foreign variables, x^*:$[i_u^*, \pi_u^*, y_u^*, i_g^*, \pi_g^*, y_g^*]$. The variables in each block have been defined in the previous section.

I treat the US and Germany as the rest-of-the-world in relation to the UK. To explain the joint dynamics of these four blocks of variables, I rewrite the forecast-augmented structural VAR model (2) block-by-block in the following matrix notation:

$$\begin{pmatrix} A_{11}^m & A_{12}^f & A_{13} & A_{14}^* \\ A_{21}^m & A_{22}^f & A_{23} & A_{24}^* \\ A_{31}^m & A_{32}^f & A_{33} & A_{34}^* \\ 0 & 0 & 0 & A_{44}^* \end{pmatrix} \begin{pmatrix} i_m \\ x^f \\ x \\ x^* \end{pmatrix} = \begin{pmatrix} B_{11}^m & B_{12}^f & B_{13} & B_{14}^* \\ B_{21}^m & B_{22}^f & B_{23} & B_{24}^* \\ B_{31}^m & B_{32}^f & B_{33} & B_{34}^* \\ 0 & 0 & 0 & B_{44}^* \end{pmatrix} \begin{pmatrix} z_m \\ z^f \\ z \\ z^* \end{pmatrix} + \begin{pmatrix} \varepsilon_t^m \\ \varepsilon_t^f \\ \varepsilon_t \\ \varepsilon_t^* \end{pmatrix}. \quad (3)$$

In the structural model (3), the restriction that $A_{41}^m = A_{42}^f = A_{43} = 0$ follows from the assumption that the other blocks of variables do not enter into the foreign block contemporaneously, and the restriction that $B_{41}^m = B_{42}^f = B_{43} = 0$ follows from the assumption that they do not enter into the foreign block in lag. This block-exogeneity assumption makes sense due to the smaller size of the UK economy compared to the total size of the US and German economies. Zha (1999) demonstrated that failing to impose such exogeneity restrictions is not only unappealing but also results in misleading conclusions. When I test the joint block-exogeneity assumption of the US and Germany in relation to the UK, I find that the null hypothesis is not rejected at a standard significance level. I also find similar results for the separate block-exogeneity test of the US and Germany.

It is easy to see from the forecast-augmented structural system (3) that, if we ignore the coefficients of the second row and the second column of the contemporaneous-coefficient matrix A and of the lagged-coefficient matrix B (that is, if $A_{21}^m = A_{22}^f = A_{23} = A_{24}^* = 0$, $A_{12}^f = A_{22}^f = A_{32}^f = 0$ and $B_{21}^m = B_{22}^f = B_{23} = B_{24}^* = 0$, $B_{12}^f = B_{22}^f = B_{32}^f = 0$), then the structural scheme boils down to a standard structural VAR model with block exogeneity, such as that of Cushman and Zha (1997) and Bhuiyan (2008). Therefore, the standard VAR model is nested in the forecast-augmented VAR model. For clarification, although the forecast-augmented model encompasses by the standard model, these are two different models, and I estimate them separately. The structural system (3) also shows that the foreign block of variables is common to the both models.

The next step is to impose identifying restrictions on the contemporaneous-coefficient matrix, A, of the structural model (2) in order to recover the structural shocks. The reduced-form version of the structural model (2) can be written as follows:

$$x_t = Ez_t + e_t, \tag{4}$$

where $E = A^{-1}F$ and $e_t = A^{-1}\varepsilon_t$. Let Σ be the variance-covariance matrix of the reduced-form residuals, e_t. Since the structural disturbances, ε_t, and the regression residuals, e_t, are related by $\varepsilon_t = Ae_t$, we can derive that:

$$\Sigma = (AA')^{-1}. \tag{5}$$

The right-hand side of equation (5) has $n \times (n+1)$ free parameters to be estimated, while the estimated variance-covariance matrix of the residuals, Σ, contains $n \times (n+1)/2$ estimated parameters. Therefore, we need at least $n \times (n+1)/2$ restrictions on the contemporaneous-coefficient matrix, A, to identify the model. Since the number of variables in the forecast-augmented model is 15, we need a total of 120 restrictions on its contemporaneous-coefficient matrix to identify the model. On the other hand, the standard model has 11 variables, and we need 65 restrictions to identify the model.

I outline the identifying restrictions on the contemporaneous-coefficient matrix, A, of the forecast-augmented model, $Ax_t = Bz_t + \varepsilon_t$, in table 2. The restrictions on each row of this table identify the within-period relationship of a variable with the other variables in the model. I do not impose any restrictions on the lagged coefficients except the block-exogeneity restrictions on the foreign block of variables, as shown in the structural model (3). Table 2 also embodies the contemporaneous identifying restrictions of the standard model: if we ignore rows and columns from 2 though 5, the table boils down to the contemporary identification scheme of the standard model.

The first row of table 2 shows the contemporaneous monetary policy equation of the forecast-augmented VAR model. In this model, I assume that the central bank contemporaneously reacts to the forecasted variables (the forecasts of the inflation rate, the exchange rate, the market interest rate, and the US federal funds rate), the realized financial variables (the market interest rate and the exchange rate), and the US and German monetary policy variables. The zero coefficients of outputs and the inflation rates for both the home and foreign countries reflect the fact that the Bank is unable to observe them within the month due to the lag in their publication.

If we ignore the coefficients corresponding to columns 2 through 5, the first row of table 2 presents the contemporaneous monetary policy identification of the standard model. Therefore, monetary policy in the standard model contemporaneously reacts to the realized values of the market interest rate and the exchange rate, as well as to the monetary policy variables of the US and Germany. The zero coefficients for outputs and the inflation rates of both the domestic and foreign countries again reflect the fact that the Bank cannot observe these variables within the month due to the lag in their publication. Therefore, the within-period identification scheme of the monetary policy equation in the standard model is the same as that of Cushman and Zha (1997) and Bhuiyan (2008).

Table 2: Contemporaneous Identification of the forecast-augmented VAR

	i_m	π^f	i^f	s^f	i_u^{*f}	i	s	y	π	i_u^*	π_u^*	y_u^*	i_g^*	π_g^*	y_g^*
i_m	a_1^1	a_1^2	a_1^3	a_1^4	a_1^5	a_1^6	a_1^7	0	0	a_1^{10}	0	0	a_1^{13}	0	0
π^f	a_2^1	a_2^2	a_2^3	a_2^4	0	a_2^6	a_2^7	0	0	0	0	0	0	0	0
i^f	a_3^1	a_3^2	a_3^3	a_3^4	0	a_3^6	a_3^7	0	0	a_3^{10}	0	0	a_3^{13}	0	0
s^f	a_4^1	a_4^2	a_4^3	a_4^4	0	a_4^6	a_4^7	0	0	a_4^{10}	0	0	a_4^{13}	0	0
i_u^{*f}	0	0	0	0	a_5^5	0	0	0	0	a_5^{10}	0	0	a_5^{13}	0	0
i	a_6^1	a_6^2	a_6^3	a_6^4	0	a_6^6	a_6^7	0	0	a_6^{10}	0	0	a_6^{13}	0	0
s	a_7^1	a_7^2	a_7^3	a_7^4	0	a_7^6	a_7^7	0	0	a_7^{10}	0	0	a_7^{13}	0	0
y	0	0	0	0	0	0	0	a_8^8	0	0	0	0	0	0	0
π	0	0	0	0	0	0	0	0	a_9^9	0	0	0	0	0	0
i_u^*	0	0	0	0	0	0	0	0	0	a_{10}^{10}	0	0	a_{10}^{13}	0	0
π_u^*	0	0	0	0	0	0	0	0	0	0	a_{11}^{11}	0	0	0	0
y_u^*	0	0	0	0	0	0	0	0	0	0	0	a_{12}^{12}	0	0	0
i_g^*	0	0	0	0	0	0	0	0	0	a_{13}^{10}	0	0	a_{13}^{13}	0	0
π_g^*	0	0	0	0	0	0	0	0	0	0	0	0	0	a_{14}^{14}	0
y_g^*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	a_{15}^{15}

Note: The a_i^j, where $i, j = 1, 2, ..., n$, are elements of of the contemporaneous-coefficient matrix A of the forecast-augmented model, $Ax_t = Bz_t + \varepsilon_t$. If we disregard rows and columns from 2 though 5, the table becomes the contemporaneous identification scheme of the standard model. Row 1 is the contemporaneous monetary policy equation, rows from 2 though 5 show contemporaneous identifications of the forecasted variables, and rows from 6 through 9 show contemporaneous identifications of the realized variables. All the remaining rows are contemporaneous equations of the foreign variables. A zero entry means that the variable in the corresponding row cannot respond to the variable in the corresponding column within the month.

The second row of table 2 shows the contemporaneous identification of the expected inflation rate equation of the forecast-augmented model. I assume that current expectations about future inflation are affected by current monetary policy actions, the market interest rate forecast, the exchange rate forecast, and the realized values of the market interest rate and the exchange rate. As monetary policy in the UK is credible, market participants believe that the Bank will take action to bring today's higher or lower inflation back to the target level.

Since monetary policy decisions affect inflation through the channels of the market interest rate and exchange rate, I assume that the forecasts of these variables as well as their realized values also influence inflation expectations within the month.

The third and the fourth rows, respectively, show the contemporary identification of the interest rate forecast equation and the exchange rate forecast equation of the forecast-augmented model. I assume that forecasts of both the market interest rate and the exchange rate affect each other within the month and are also affected by current monetary policy changes, inflation expectations, realized market interest rate, realized exchange rate, and foreign monetary policy decisions.

The seventh and the eighth rows of table 2, excluding the elements corresponding to columns 2 through 5, show the contemporaneous identification of the market interest rate equation and the exchange rate equation of the standard model. These variables in the standard model affect each other and are also affected by the monetary policy decisions of both the home and foreign countries. In the forecast-augmented model, in addition to these variables, the forecasts of the inflation rate, the market interest rate, and the exchange rate also affect the realized market interest rate and the realized exchange rate. The eight and the ninth rows, respectively, are the contemporaneous identification of output and the inflation rate equations. I assume that output and the realized inflation rate in both the standard and the forecast-augmented models neither affect other variables nor are affected by other variables within the month.

Rows 10 through 15 show the contemporaneous identification scheme of the foreign block of equations. The identification of this block of variables is invariant across the forecast-augmented and the standard models. The domestic forecasted and realized variables do not affect the exogenous foreign variables. The contemporaneous-exogeneity assumption of the foreign variables is shown by the zero restrictions on the coefficients of all the domestic variables in the equations of the foreign variables. Since both the US and Germany are large countries, I assume that a monetary policy decision in one country affects the policy decision of another country within the month. On the other hand, output and the inflation rate of the US and Germany neither affect the other variables nor are affected by the other variables within the period due to the lag in publication of these variables.

4.2 A Bayesian Approach of Imposing Restrictions and Estimation

Two circumstances unfold from the identification scheme in the previous subsection.

First, I allow more simultaneous interactions in the contemporaneous relationship of the variables of both the forecast-augmented and the standard VAR models. This higher degree of simultaneous interaction makes my structural models different and perhaps more realistic than existing structural VAR models such as those of Cushman and Zha (1997) and Kim and Roubini (2000). Second, in both VAR models, I have imposed over-identifying restrictions. For example, while a total of 120 zero restrictions on the contemporaneous-coefficient matrix, A, of the forecast-augmented model would exactly identify the model, I have imposed 164 zero restrictions, which makes the covariance matrix of the reduced-form residuals, Σ, restricted. I test the over-identifying restrictions in the next section. Once again, I clarify that I estimate the forecast-augmented VAR model and the standard model separately, although the latter model is encompassed in the former model.

Due to the high degree of simultaneous interaction in these over-identified VAR models, the shape of the posterior density of the parameters tends to be non-Gaussian. As a result, the widely used importance sampling method of obtaining finite-sample inferences becomes inefficient, as noted by Leeper, Sims, and Zha (1996) and Zha (1999). Waggoner and Zha (2003) demonstrated how the use of the importance sampling method in a simultaneously interacted over-identified model results in misleading inferences. Therefore, I do not use the existing importance sampling technique as did Cushman and Zha (1997) and Kim and Roubini (2000), although their identification approaches also had simultaneous interactions but to a lesser extent than in my approach.

To circumvent the problem incurred due to the simultaneity involved in these over-identified structural VAR models, I estimate them following the Bayesian Gibbs sampling method of Waggoner and Zha (2003), who incorporated prior information into the VAR as suggested by Sims and Zha (1998). The advantage of this approach is that it delivers accurate statistical inferences for models with a high degree of simultaneity among the contemporaneous variables, as well as for models with restricted variance-covariance matrices of the residuals and for models with restrictions on lagged coefficients.

To explain how the Gibbs sampling method can be applied, let a_i be the ith row of the contemporaneous-coefficient matrix, A, and f_i be the ith row of the lagged-coefficient matrix, F, defined in the structural equation (2), where $1 \leqslant i \leqslant n$. Let Q_i be any $n \times n$ matrix of rank q_i, and R_i be any $k \times k$ matrix of rank r_i. Therefore, the linear restrictions on the contemporaneous-coefficient matrix, A, and on the lagged-coefficient matrix, F, can be summarized, respectively, as follows:

$$Q_i a_i = 0, \quad i = 1, ...n, \tag{6}$$

$$R_i f_i = 0, \quad i = 1, ...n. \tag{7}$$

Assuming that there exist non-degenerate solutions to the above problems, I can define a $n \times q_i$ matrix U_i whose columns form an orthonormal basis for the null space of Q_i, and a $k \times r_i$ matrix V_i whose columns form an orthonormal basis for the null space of R_i. Therefore, a_i and f_i, which, respectively, are the rows of A and F, will satisfy the identifying restrictions (7) and (8) if and only if there exists a $q_i \times 1$ vector b_i and a $r_i \times 1$ vector g_i such that

$$a_i = U_i b_i, \tag{8}$$

$$f_i = V_i g_i. \tag{9}$$

The model then becomes much easier to handle by forming priors on the elements of b_i and g_i, since the original parameters of a_i and f_i can be easily recovered via the linear transformations through U_i and V_i. Waggoner and Zha (2003) demonstrated that by using this approach simulations can be carried out on an equation-by-equation basis, which vastly reduces the computational burden of the problem. To obtain the finite-sample inferences of b_i and g_i, and their functions, that is, impulse responses, it is necessary to simulate the joint posterior distribution of b_i and g_i. To do this simulation, I follow Waggoner and Zha's (2003) two-step Gibbs sampling procedure.[4] First, I simulate draws of b_i from its marginal posterior distribution, and then, given each draw of b_i, I simulate g_i from the conditional posterior distribution of g_i. The second step is straightforward, since it requires draws from multivariate normal distributions. The first step, however, is less straightforward, as the over-identifying restrictions on the contemporaneous-coefficient matrix, A, makes reduced-form covariance matrix, Σ, restricted.

5. Empirical Evidence of the Effects of Monetary Policy Shocks

First, I report the results of the over-identifying restrictions imposed on the contemporaneous and the lagged coefficients. Following Cushman and Zha (1997), I perform a joint test of the contemporaneous and the lagged identifying restrictions. As long as all restrictions are treated as a restricted subset of the complete unrestricted parameter space, the likelihood ratio test can be applied to test the overall identifying restrictions. In the forecast-augmented model, the contemporaneous-coefficient matrix, A, has 44 over-identifying restrictions, and

[4] For a detailed explanation of the algebra and algorithm, see Waggoner and Zha (2003).

with a lag-length of 6, the number of lagged restrictions on the foreign block is 360. Therefore, with a total of 404 restrictions, the estimated Chi-squared statistic $\chi^2(404) = 402.543$ implies that the null cannot be rejected at a standard significance level. Similarly, the estimated Chi-squared statistics for the standard models is $\chi^2(155) = 149.543$, implying that the null hypothesis is not rejected at a usual significance level for this model as well.

Next, I report the estimated results of the forecast-augmented model. As I have discussed in subsection 4.1, apart from identifying a forward-looking policy rule, a greater degree of simultaneous interactions among the variables makes the structural approach developed in this paper different from the existing approaches in the literature. Therefore, the estimated contemporaneous coefficients will be informative about the effectiveness of both identifying the forward-looking monetary policy and allowing simultaneous interactions among variables.

The estimated contemporaneous coefficients of the forecast-augmented structural VAR model are reported in table 3. I do not present the estimated coefficients of the equations of the foreign variables, since I am interested only in the equations of the domestic variables. Lines 1 through 6 of table 3 are the estimated coefficients of the monetary policy equation, the expected inflation equation, the interest rate forecast equation, the exchange rate forecast equation, the realized market interest rate equation, and the realized exchange rate equation respectively. We observe from line 1 that all the contemporaneous coefficients of the forecasted variables in the monetary policy reaction function are statistically significant at less than the 0.05 level. Therefore, a policy function identified without using these forecasts will produce incorrect policy shocks, which in turn will generate misleading impulse responses. We also see that most of the simultaneously interacted coefficients are statistically significant at the 0.05 level. The significance of the simultaneously interacted coefficients indicates that both a recursive identification that cannot incorporate simultaneous interactions and a structural identification that does not include these simultaneous interactions will be erroneous.

In the monetary policy equation, the coefficient of the expected inflation rate in negative, and this sign will be positive if this variable is moved to the right-hand side of the monetary policy equation. This sign changing rule is true for all the coefficients reported in table 3. The negative and significant coefficient of the expected inflation rate implies that the Bank of England tightens monetary policy upon observing higher inflation expectations. Since the key objective of the Bank is to maintain a stable inflation rate at around 2 percent, contracting monetary policy after forecasting a higher inflation rate is consistent with the

Bank's inflation-targeting policy. On the other hand, the positive and significant coefficient of the market interest rate forecast means that the central bank tightens monetary policy if it forecasts a lower interest rate. The negative and significant coefficient of the exchange rate forecast indicates that the Bank increases the bank rate upon forecasting any currency depreciation. Since both the lower market interest rate and the depreciation of the pound sterling are indications of future inflation, tightening monetary policy under these circumstances is also consistent with the Bank's commitment to maintain a stable inflation rate. We also see that the coefficient of the federal funds rate forecast is negative and significant, implying that the central bank increases the bank rate after forecasting a higher federal funds rate.

Table 3: Estimated contemporaneous coefficients of the forecast-augmented model

	i_m	π^f	i^f	s^f	i_u^{*f}	i	s	i_u^*	i_g^*
	a_1^1	a_1^2	a_1^3	a_1^4	a_1^5	a_1^6	a_1^7	a_1^{10}	a_1^{13}
i_m	1.132	−0.842	0.774	−2.423	−0.247	0.695	0.814	−0.192	−0.156
	(0.423)	(0.212)	(0.357)	(1.114)	(0.110)	(0.304)	(0.408)	(0.095)	(0.092)
	a_2^1	a_2^2	a_2^3	a_2^4	a_2^5	a_2^6	a_2^7	a_2^{10}	a_2^{13}
π^f	0.649	3.441	4.876	−1.659	0	3.463	−0.873	0	0
	(0.296)	(1.032)	(3.098)	(0.873)	–	(1.569)	(0.276)	–	–
	a_3^1	a_3^2	a_3^3	a_3^4	a_3^5	a_3^6	a_3^7	a_3^{10}	a_3^{13}
i^f	−6.342	−2.345	1.124	−1.084	0	0.984	−1.267	−0.985	−0.739
	(2.456)	(1.843)	(0.436)	(0.486)	–	(0.398)	(0.574)	(0.627)	(0.583)
	a_4^1	a_4^2	a_4^3	a_4^4	a_4^5	a_4^6	a_4^7	a_4^{10}	a_4^{13}
s^f	4.854	−3.326	0.974	8.984	0	0.927	0.968	−1.349	−0.985
	(1.323)	(1.765)	(0.347)	(3.983)	–	(0.432)	(0.239)	(0.564)	(0.462)
	a_6^1	a_6^2	a_6^3	a_6^4	a_6^5	a_6^6	a_6^7	a_6^{10}	a_6^{13}
	−5.942	−2.648	1.723	−1.194	0	0.975	−1.387	−0.916	−0.790
i	(2.251)	(1.140)	(0.530)	(0.721)	–	(0.379)	(0.614)	(0.497)	(0.583)
	a_7^1	a_7^2	a_7^3	a_7^4	a_7^5	a_7^6	a_7^7	a_7^{10}	a_7^{13}
s	3.951	−3.129	0.871	7.973	0	0.729	0.968	−1.809	−0.916
	(1.873)	(1.485)	(0.447)	(3.793)	–	(0.372)	(0.239)	(0.394)	(0.619)

Note: Entries correspond to row 1 through row 4 and row 6 through 7 of the contemporaneous-coefficient matrix, A, identified in table 2, and apply to shocks to i_m, π^f, i^f, s^f, i, and s, respectively. Entries within brackets are standard errors. The sign of these coefficients will be the opposite if the corresponding variables are moved to the right-hand side of the equation.

We observe from row 1 of table 3 that the coefficients of the domestic realized and the foreign variables in the monetary policy function, except for the monetary policy variable of Germany, are also significant. The positive coefficient of the realized market interest rate implies that the Bank contracts monetary policy upon observing a lower market interest rate. Similarly, the negative coefficient of the exchange rate means that the Bank increases the bank rate after observing a depreciation of the pound sterling. These responses of the central bank are also consistent with its inflation-targeting policy. On the other hand, the negative coefficients of the foreign policy variables confirm the traditional belief that an open-economy's central bank follows large countries' policy rules.

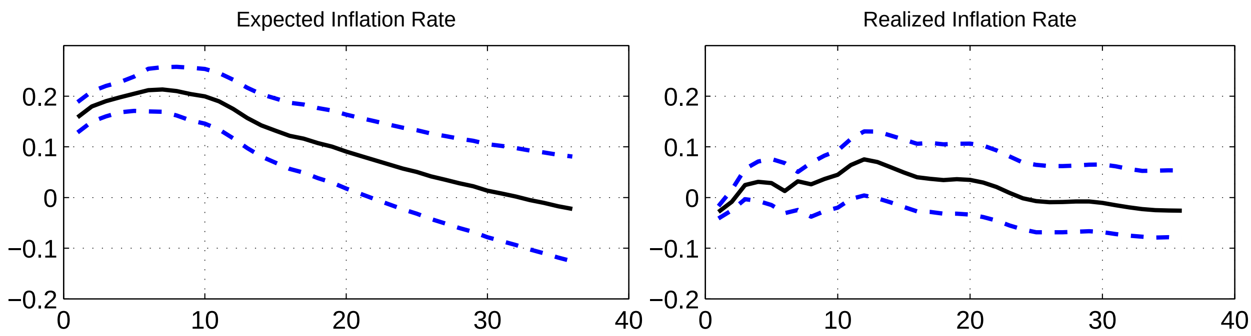
Column 1 of table 3 shows contemporaneous monetary policy effects on various macroeconomic variables. The positive and significant coefficient of the bank rate on the inflation forecast equation indicates that expectations about future inflation go down due to a rise in the bank rate. The negative and significant coefficient of the bank rate on the interest rate forecast equation shows that a contractionary monetary policy increases public forecasts about future market interest rates. Similarly, the positive and significant coefficient of the policy variable on the exchange rate forecast equation means that monetary tightening causes market participants to forecast an appreciation of the pound sterling. As we notice from column 1, the bank rate has similar contemporaneous effects on the realized market interest rate and the realized exchange rate as it has on their forecasts.

Most of the other contemporaneous coefficients of the forecast-augmented model are also statistically significant at the 0.05 level and have expected signs. However, the coefficient of the interest rate forecast on the inflation forecast equation, the coefficients of both the foreign policy variables on the interest rate forecast equation, the coefficient of the exchange rate forecast on the market interest rate equation, and the coefficient of the German policy variable on the exchange rate equation, are statistically insignificant. Although these coefficients are not significant at the 0.05 level, most of them are not highly insignificant either, and they all have expected signs. Therefore, I assume that these variables interact with each other within the month.

Next, I discuss the impulse responses. First, I report the reaction of the central bank's policy variable due to shocks to the expected inflation rate and the realized inflation rate in figure 4. The left panel of the figure shows the impulse responses of the policy variable due shocks to inflation expectations, while the right panel shows the response due to shocks to actual inflation. Both panels are drawn on the same scale. The horizontal axis measures the response horizon in months. The solid lines are the estimated impulse responses, and the upper and lower dashed lines are one-standard-deviation error bands, derived using the

Bayesian Gibbs sampling method of Waggoner and Zha (2003).[5] The figure shows that due to a one-standard deviation shock in inflation expectations, the bank rate increases by 20 basis points, and the effect remains significant for about two years. On the other hand, the increase in the bank rate due to the shock to the realized inflation rate is statistically insignificant as well as smaller in magnitude (about 8 basis points). These results—the significant policy response due to the expected inflation shock and the insignificant policy response due the realized inflation shock—reflect the forward-looking policy behaviour of the Bank of England. These differential policy responses make sense because the Bank knows that it can affect inflation only with a lag, so the rational action would be to respond to the forecast of future inflation rather than current inflation. Therefore, any VAR models that do not use inflation expectations as policy inputs will estimate erroneous policy shocks and hence will generate misleading impulse responses.

Figure 4: Policy Responses Due to Shocks to Expected and Realized Inflation



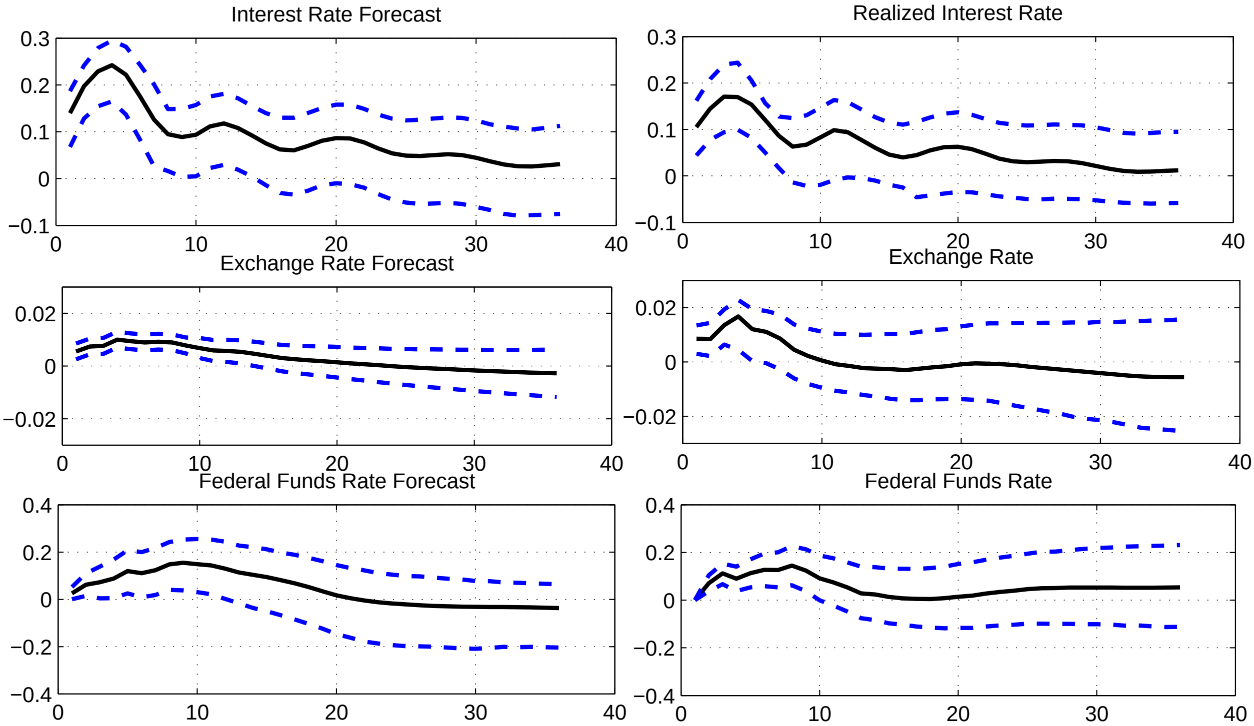
Note: Both figures are drawn on the same scale. The solid lines are point estimates of the impulse responses of the policy variable due to shocks in forecasted and realized inflation. The dashed lines are one-standard-deviation error bands.

I contrast the impulse responses of the policy variable due to shocks to the other forecasted and realized variables in figure 5. The left panels show the responses of the policy variable due to shocks in the forecasted variable, and the right panels show the responses due to shocks in the realized variables. These graphs are also drawn on the same scale. We observe that the Bank significantly responds to both the forecasts and their realized values. However, shocks in the forecasted variables seem to have more persistent and significant effects on the policy variable than do shocks in the realized variables. We see that the bank rate increases due to shocks in both the interest rate forecast and the realized interest rate, although the magnitude of the policy response is higher in the former than the latter. The Bank also tightens monetary policy upon forecasting a depreciation of the British pound and

[5]The error bands are computed from a set of 10,000 draws. I gratefully acknowledge Tao Zha for helping me with the Matlab codes.

upon observing the current depreciation of the British pound. The figure also shows that the Bank contracts monetary policy upon forecasting a higher federal funds rate or if there is a positive shock in the current federal funds rate.

Figure 5: Policy Responses Due to Shocks to Forecasted and Realized Variables

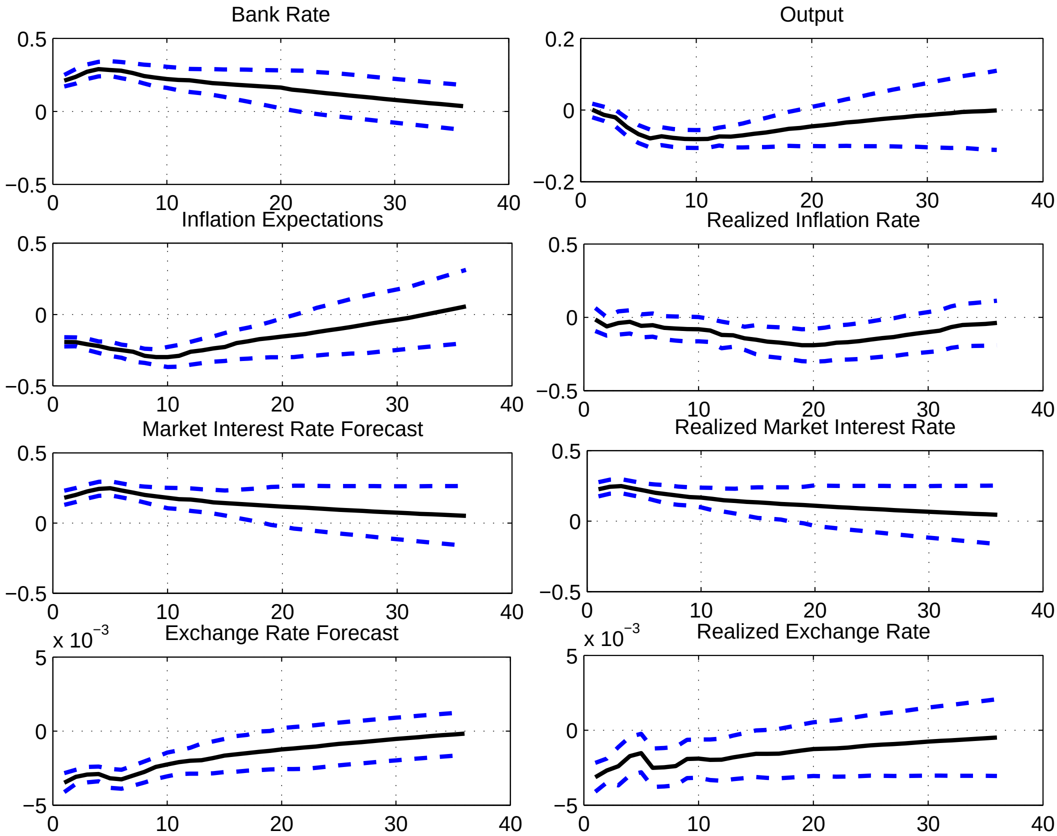


Note: The left and the right panels of the figure are drawn on the same scale. The solid lines are point estimates of the impulse responses of the policy variable due to shocks in forecasted and realized variables. The dashed lines are one-standard-deviation error bands.

Finally, I report the impulse responses of the forecasted and the realized macroeconomic variables due to shocks in the policy variable in figure 6. We find that a one-standard deviation shock of increasing the bank rate by about 30 basis points increases both the forecast of the market interest rate and the realized market interest rate by about 25 basis points, and the effects remain significant for about 18 months. Following the same shock, both the pound sterling and the forecast of the pound sterling appreciate on impact and then gradually depreciate towards the terminal value. Therefore, these impulse responses are consistent with Dornbusch's (1976) prediction that following a policy shock the exchange rate overshoots its long-run level on impact, followed by a gradual adjustment to the initial value.

We also observe that the contractionary policy shock lowers the level of output with a lag of about one year. Finally, this policy shock reduces the expected inflation rate by about 30 basis points and the realized inflation rate by about 15 basis points. The interesting result, however, is that, while the contractionary policy shock affects inflation expectations immediately (although the effect peaks after about six months), the policy shock affects the realized inflation rate only with a lag. The quicker response of inflation expectations reflects the credibility of the Bank of England's monetary policy: the public trusts that the Bank's action will bring today's higher inflation down to the target level in the future, so they expect a lower inflation rate in the future. And, indeed, this expectation seems very realistic, as we observe from the impulse response function of the realized inflation rate: following the contractionary policy shock, the inflation rate starts to fall at the beginning of the second year, and the effect peaks towards the end of the second year.

Figure 6: Impulse Responses Due to Policy Shocks in the Forecast-augmented Model



Note: The solid lines are point estimates of the impulse responses of the forecasted and realized variables due to a one-standard-deviation shock to the bank rate in the forecast-augmented model. The dashed lines are one-standard-deviation error bands.

Apart from impulse responses, variance decompositions are also useful tools to identify the variables that influence monetary policy decisions. I report the variance decomposition of the bank rate due to shocks to the forecasted variables, the realized variables, and the foreign variables in table 4. We see that at almost all horizons the block of the forecasted variables explains a higher portion of the movement of the bank rate than do shocks to the block of the realized variables. When I disaggregate the total share of the forecasted variables, I find that the relative share of inflationary expectation shocks underlying the fluctuations of the policy variable is higher than shocks to the other forecasted variables. These results reflect the importance of using the macroeconomic forecasts as inputs to the monetary policy reaction function and also stress the significance of inflationary expectations over other macroeconomic forecasts.

Table 4: Variance decomposition of the policy variable in the forecast-augmented model

.

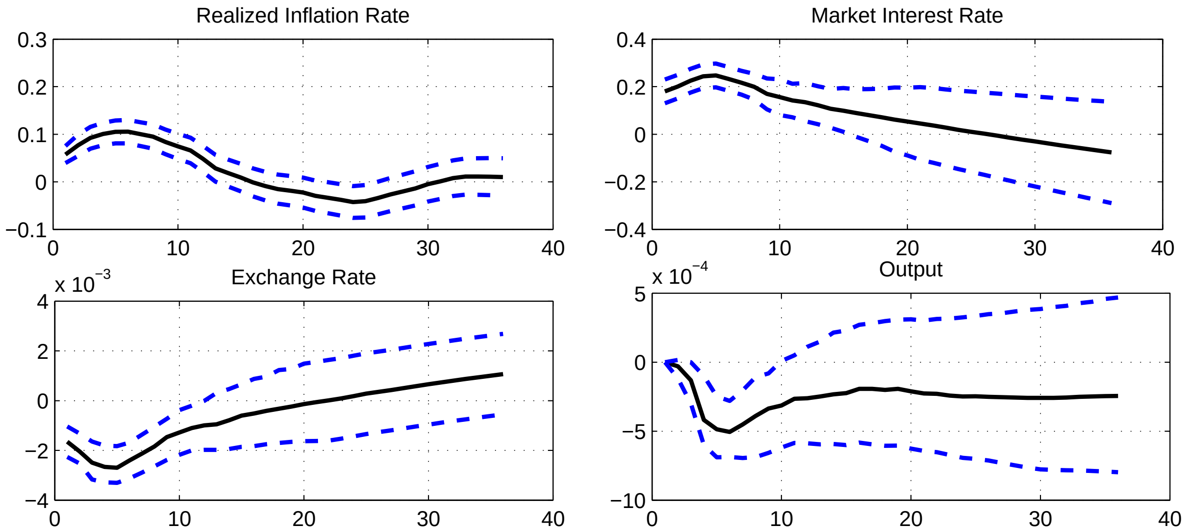
Months	x^f	=	$[\pi^f + i^f + s^f]$	x^r	x^*
1	**9.02**	=	$[4.27 + 3.88 + 0.87]$	**3.88**	**2.98**
6	**28.14**	=	$[13.56 + 11.96 + 2.62]$	**18.04**	**16.24**
12	**32.46**	=	$[20.45 + 9.87 + 2.14]$	**29.87**	**21.96**
24	**36.76**	=	$[25.14 + 8.99 + 2.63]$	**31.38**	**28.65**
48	**34.08**	=	$[23.19 + 9.09 + 1.80]$	**35.23**	**29.54**

Note: Bold entries (in percentage points) on the second, fourth and fifth columns, respectively, are the proportions of the movements of the bank rate explained by the forecasted, realized, and foreign block of variables. Entries in the middle column are shares of the individual forecasted variables.

I also examine the robustness of the results to a number of changes in the identification. First, I re-estimate the model imposing zero restrictions to the coefficients that are not significant at the 0.05 level. I find that the overall qualitative results due to the imposition of the zero restrictions are robust. However, the impulse response function of the exchange rate due to the policy shock becomes less significant if the contemporaneous coefficient of the German policy variable in the monetary policy equation is zero. I also re-estimate the model excluding the federal funds rate forecast. Again, while the overall pattern of impulse responses remains unchanged due to this exclusion, the response of the exchange rate due to the policy shock becomes less significant. These findings might imply that the exchange rate is an important channel through which shocks from both home and abroad spill over to the rest of the economy, as was found by Kim (2005) and Bhuiyan (2008).

Next, I report the results of the standard model nested in the forecast-augmented model. The comparison of the impulse responses of the realized variables in the standard model with those in the forecast-augmented model will provide useful insights about the contribution of identifying the forward-looking monetary policy employing macroeconomic forecasts. The impulse responses of the standard model are reported in figure 7. We see that while the impulse responses of the market interest rate and output remain unchanged from those of the forecast-augmented model, there is a remarkable change in the impulse responses of both the realized inflation rate and the exchange rate. The figure shows that following a contractionary monetary policy shock, the realized inflation rate increases and remains significant for about one year. This response is at odds with what we expect from a contractionary monetary policy shock. On the other hand, following the same shock, the British pound keeps appreciating for about six months after the shock. This response of the exchange rate is inconsistent with Dornbusch's (1976) prediction that following a contractionary policy shock the exchange rate overshoots its long-run level on impact, followed by a gradual adjustment to the initial value.

Figure 7: Impulse Responses Due to Policy Shocks in the Standard Model



Note: The solid lines are point estimates of the impulse responses of the forecasted and realized variables due to a one-standard-deviation shock in the bank rate in the standard VAR model. The dashed lines are one-standard-deviation error bands. These impulse responses are comparable to the impulse responses of the realized variables in the forecast-augmented model reported in the right panel of figure 5.

Next, I investigate which aspect of the forecast-augmented VAR model absent from the standard model causes the puzzling response of the inflation rate and the delayed response of the exchange rate. I incorporate the forecasted variables into the standard model one after another and check the impulse responses. I find that the incorporation of the expected inflation rate reverses the initial response of the inflation rate, while the inclusion of both the interest rate forecast and the exchange rate forecast removes the delayed overshooting response of the exchange rate.

This finding—that the inclusion of expected inflations as policy inputs reverses the puzzling response of the inflation rate—indicates that a policy function identified without inflation expectations will estimate policy shocks that embody the endogenous policy response of the central bank. As explained by Sims (1992), since the endogenous policy response to future inflationary forces partially offsets the inflation rate, an econometrician's policy reaction function excluding inflation expectations is likely to produce the puzzling impulse response of the inflation rate. On the other hand, the pioneering work by Obstfeld and Rogoff (1995) and a number of subsequent studies, such as those by Chari, Kehoe, and McGrattan (2002), Corsetti and Pesenti (2001), Galí and Monacelli (2004), and Kollmann (2001) argued that the monetary transmission mechanism operates through the channels of market interest rate and exchange rate. Therefore, the forecasts of these variables might also be considered by a central bank while making policy decisions, and a policy function identified without using them might be incorrect. The exclusion of these forecasts might explain the delayed overshooting response of the exchange rate found in some previous studies, such as those of Grilli and Roubini (1995), Eichenbaum and Evans (1996), and Faust and Rogers (2003).

6. Conclusion

I develop a forecast-augmented VAR model for an open economy using forecasts of key macroeconomic variables, in addition to the realized variables used in a standard VAR model. Two specific results suggest that forecasted variables play a greater role than realized variables in identifying the monetary policy function. First, the impulse responses of the policy variable suggest that monetary policy responds to shocks in forecasted variables more significantly than shocks in realized variables. Second, the variance decomposition also shows that shocks to inflationary expectations and other forecasts explain a higher proportion of the movements of the policy variable than do shocks to realized variables. In the forecast-augmented model, I also find that a contractionary policy shock almost instantaneously increases the market interest rate as well as the forecast of the market interest rate. This policy shock also appreciates both the British pound and the forecast of the pound on impact. On the other hand, while the contractionary policy shock lowers the expected inflation rate immediately, the shock affects the realized inflation rate with a lag of eighteen months. I also find that the policy shock lowers the level of output with a lag of about one year.

When I estimate the standard model nested in the forecast-augmented model I find that, following a contractionary monetary policy shock, the realized inflation rate increases for about a year, and the British pound keeps depreciating for about half a year. The important result, however, is that the inclusion of inflation expectations into the standard VAR reverses the puzzling response of the inflation rate, and the inclusion of both the market interest rate forecast and the exchange rate forecast removes the delayed overshooting response of the exchange rate. These findings suggest that a standard VAR may incorrectly identify the policy reaction function and hence generate misleading results.

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